Συνεργεια

FNAL Booster Modeling & Data Comparisons

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Outline

- Experimental program objectives
- Studies & comparisons with Synergia
- Plans/future options

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Objectives

- Code "reality check"
- Maintain connection with real machine issues
  - drive physics implementation
  - guide simulation input/setup, analysis software
- Have impact on understanding operating accelerators
  - ⇨ Cannot control all parameters of operating accelerator. Instead, produce a multi-dimensional map of performance vs input parameters & different physics and compare to data

⇨ Maintain balance of studies & code development!

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Booster studies: a test example

- *"Space charge effects responsible for Booster loses at ~1ms"*, common wisdom
  - ⇨ great opportunity to test code & do useful physics
- → Study space-charge (begin summer 2002)
- → But first, understand machine instrumentation & code performance
  - → calibrate instrumentation response
  - → run with "simple" input conditions

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Possibilities for studies (1)

- Measure beam size turn by turn, for different beam currents
- Existing instrumentation:
  - Ionization Position Monitor (IPM)
  - Resistive Wall Monitor (RWM)
- IPM response depends on current, need to calibrate -> flying beam!

⇨ studies could be parasitic (but is easier to model in DC)

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Possibilities for studies (2)

- Tune shift as a function of charge
  - cleaner measurement (quad current scan, only beam charge measurement required)
  - harder to model/interpret

    … but a nice challenge for the simulation & good motivation for code development

⇨ can only be dedicated (DC mode & change of lattice)

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Possibilities for studies (3)

- Profiles from MWPC @ an extraction line
  - running DC, changing extraction time to measure different turn #
  - highly disruptive
- other options not yet considered...
  - is it worthwhile pursuing such highly disruptive options?

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Accomplishments to date

- Developed calibration technique for IPM
  - calibrated horizontal IPM
- Developed analysis tools for raw IPM data
  - ⇨ have the ability to monitor machine performance
- Study longitudinal profile evolution (RWM)
- Study transverse profile evolution
  - correlate to losses; varying machine conditions
- Study resonance vs machine current

➔ highlights in the following…

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Profile measurement studies

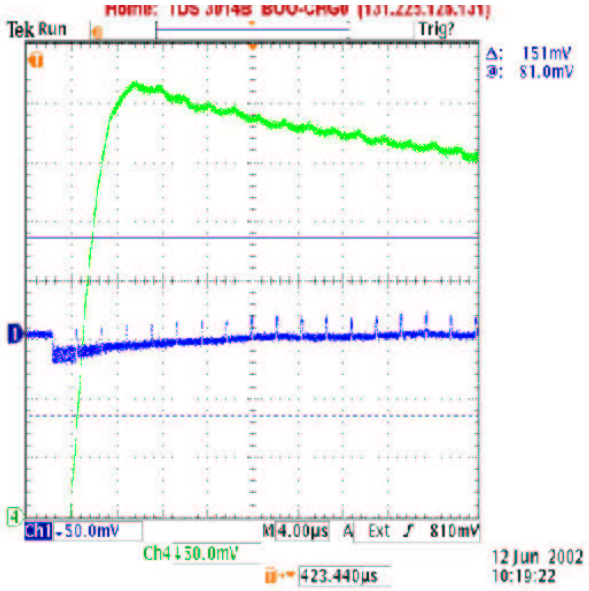
I. Single turn injection, 10-42 mA beam current from Linac quad tuning

- RF off, machine running DC, use RWM, wire and IPM

II. Multi-turn injection

- RF para phased, machine ramping (IPM, wire and MWPC)

III. Normal machine operation (IPMP)



"Flying Beam" Wire

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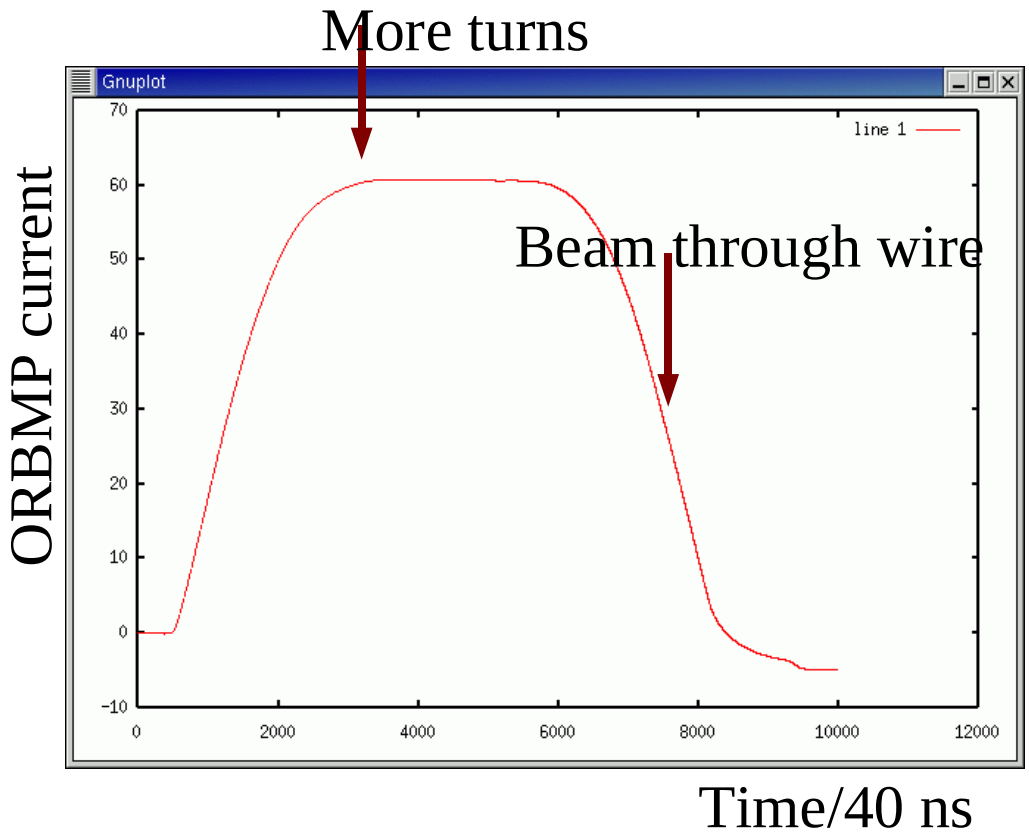
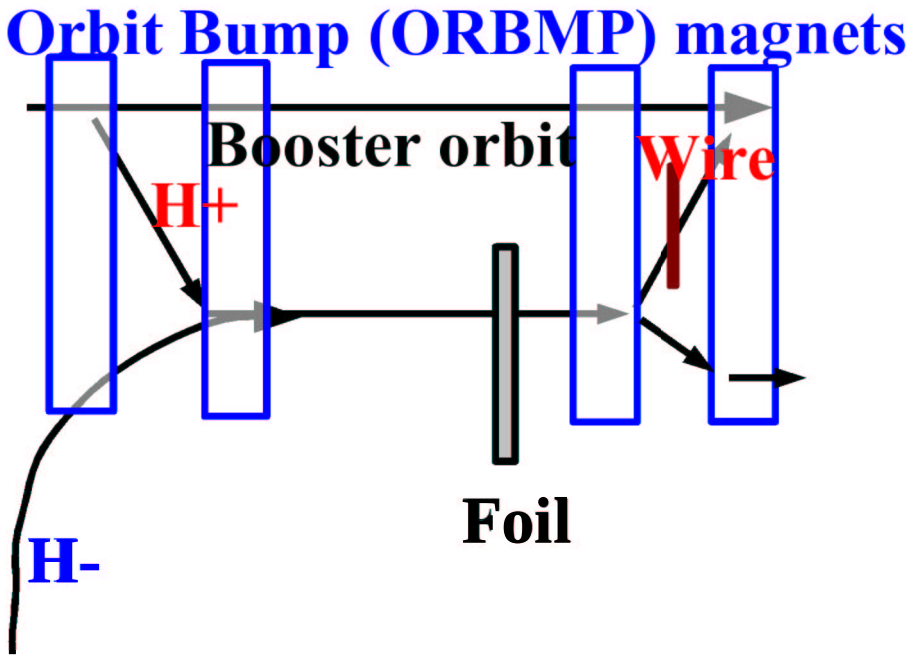
Change time of injected beam relative to ORBMP:





Each turn # a different measurement

Longitudinal PhS using the RWM

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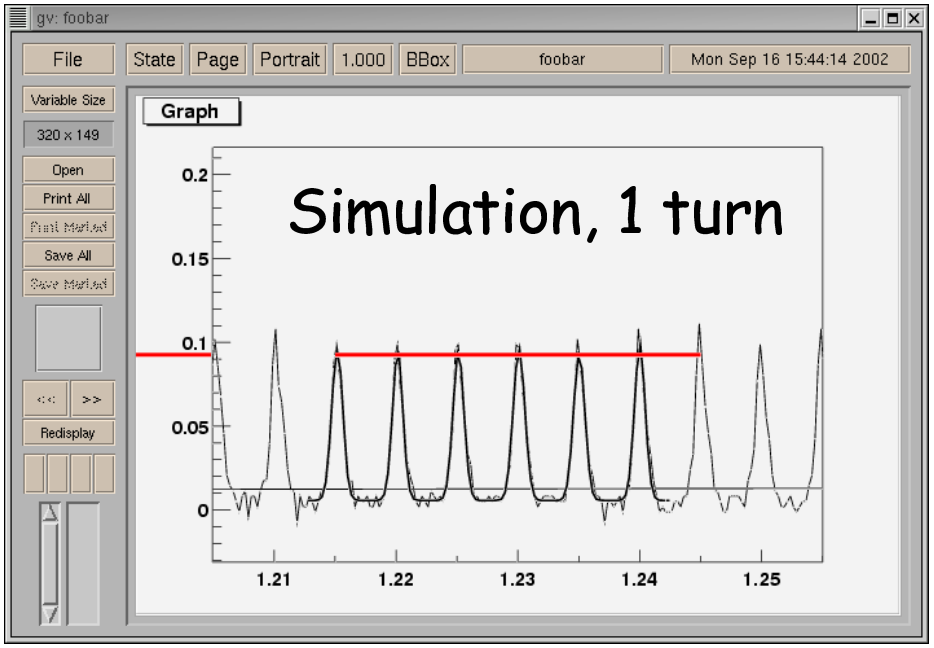
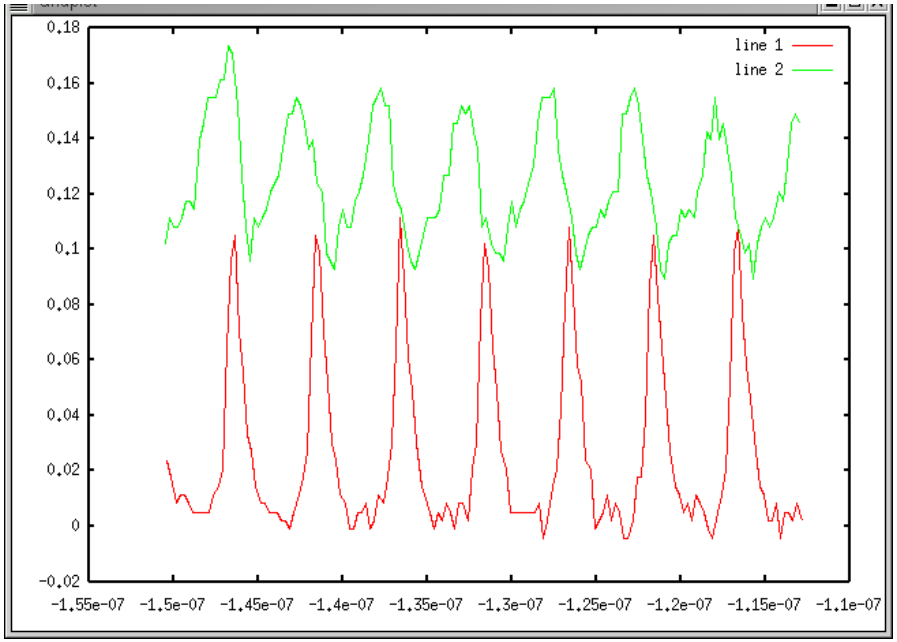


Good qualitative agreement

Data, $\frac{3}{4}$ turn, 3.75 turns, with 3 turns added



Data includes random offset present at multi-turn injection

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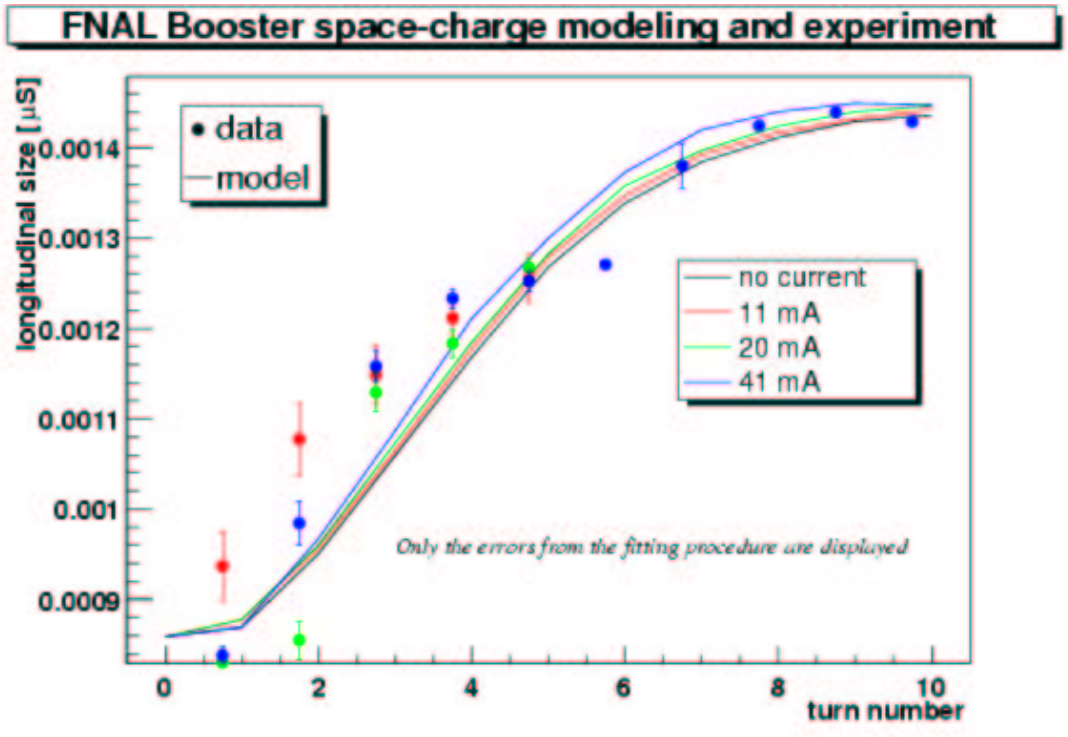
Longitudinal PhS evolution



From single turn experiment:

beam RMS vs turn #

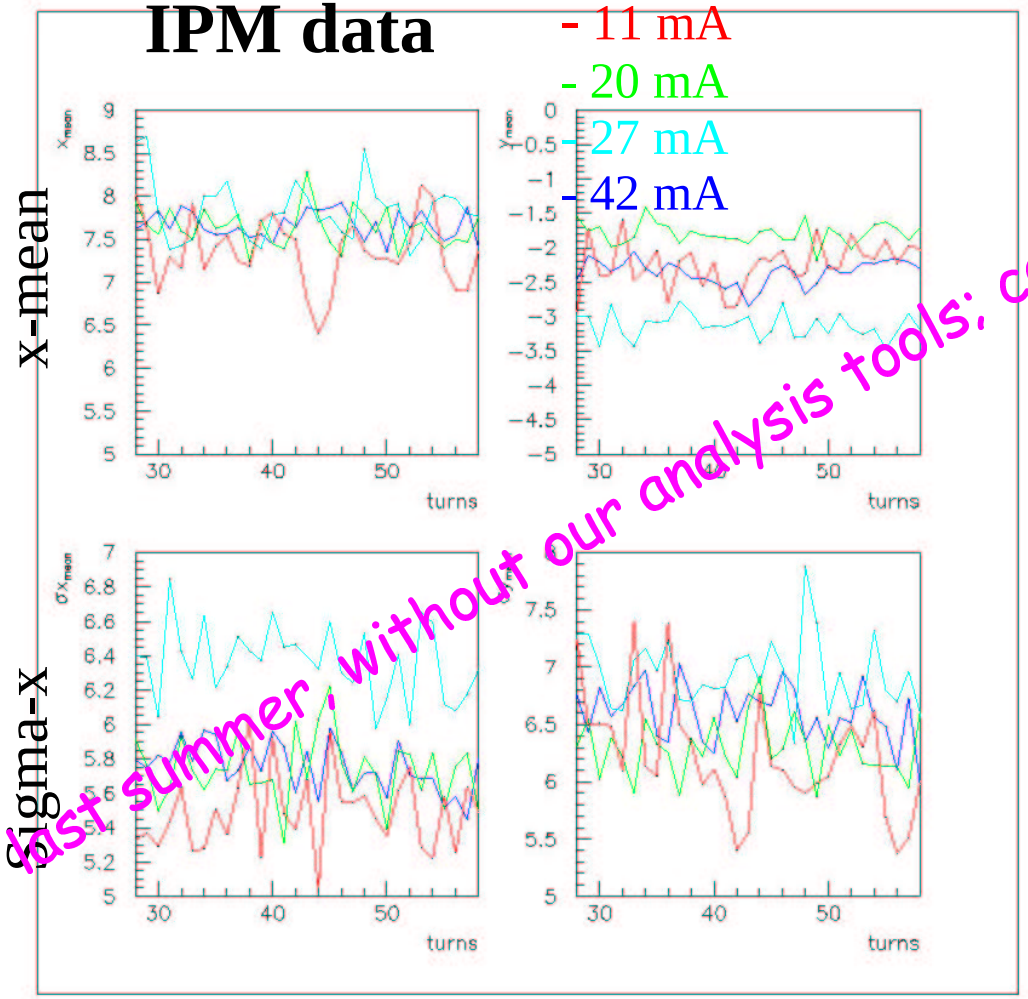
- Model describes data for Dp/p ~ 0.0002
- No space charge effects expected or observed for 11-41 mA

Error bars represent fitting uncertainty only

How about transverse?

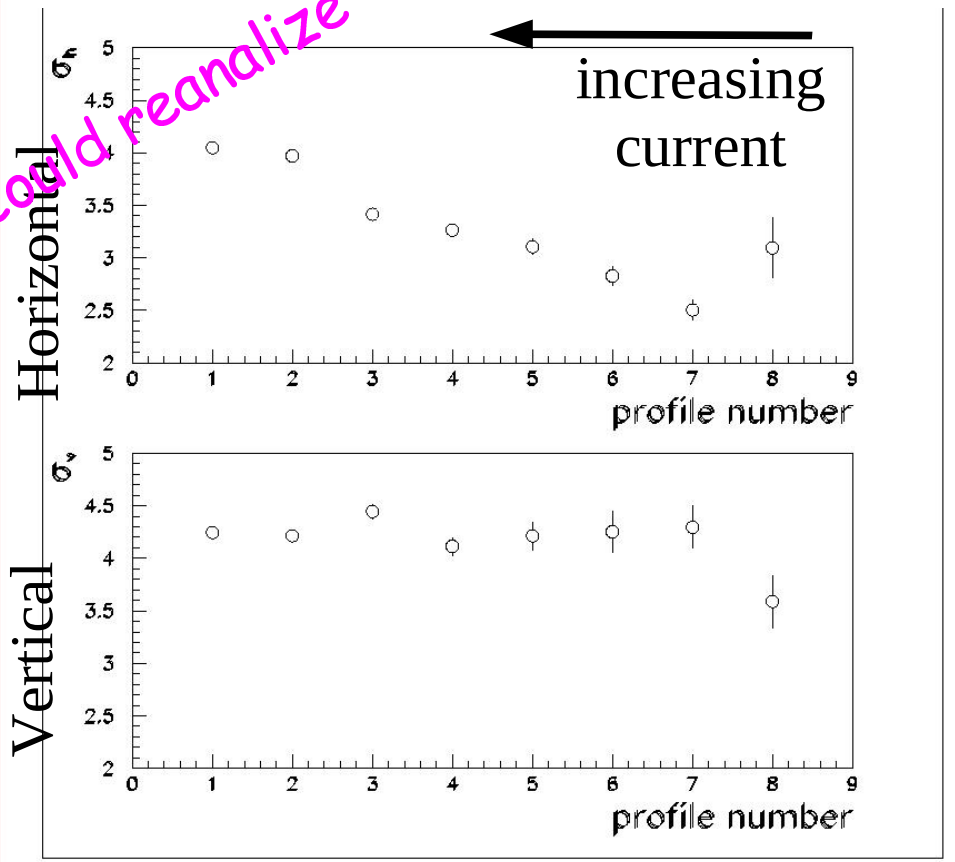
IPM data

- 11 mA
- 20 mA
- 27 mA
- 42 mA



last summer, without our analysis tools; could reanalize

Injection line MWPC sigmas



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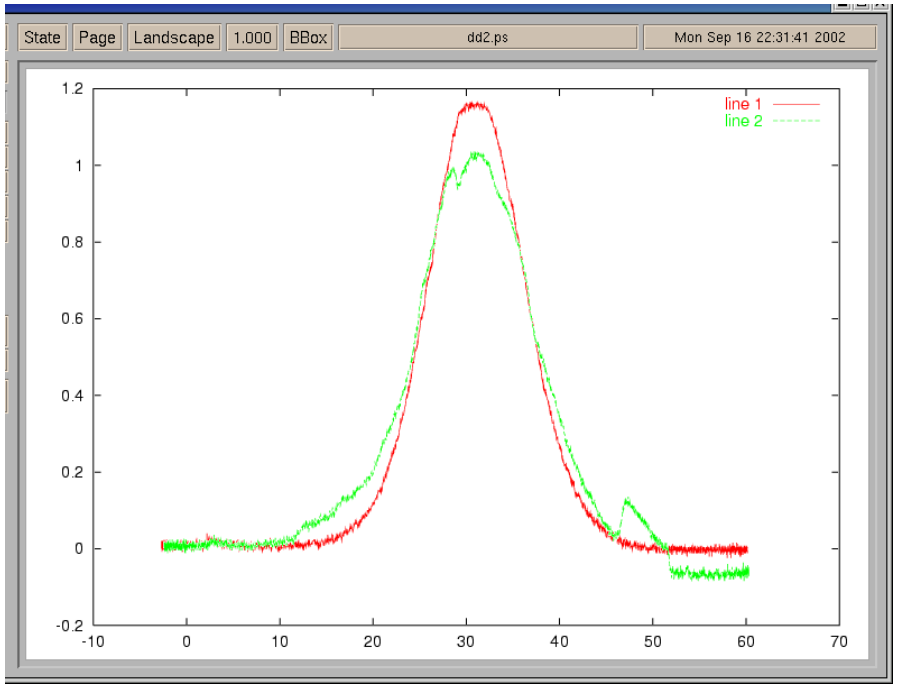
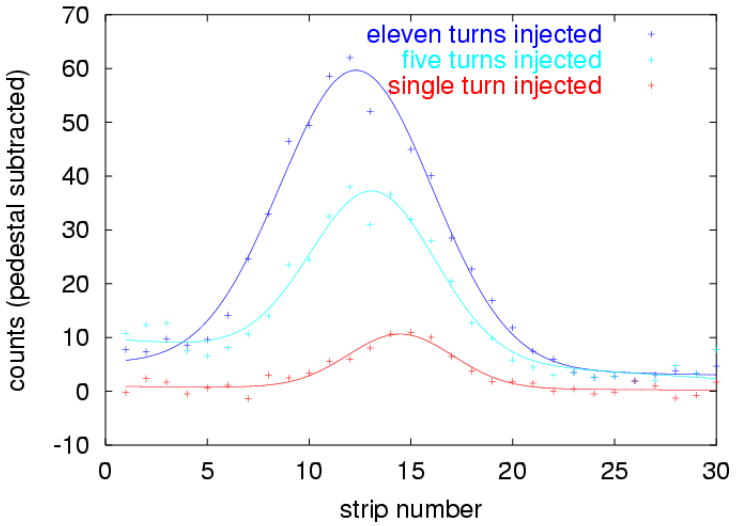
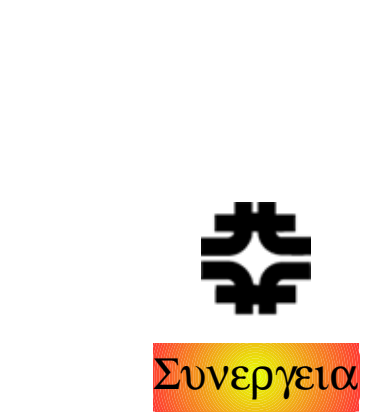
IPM calibration

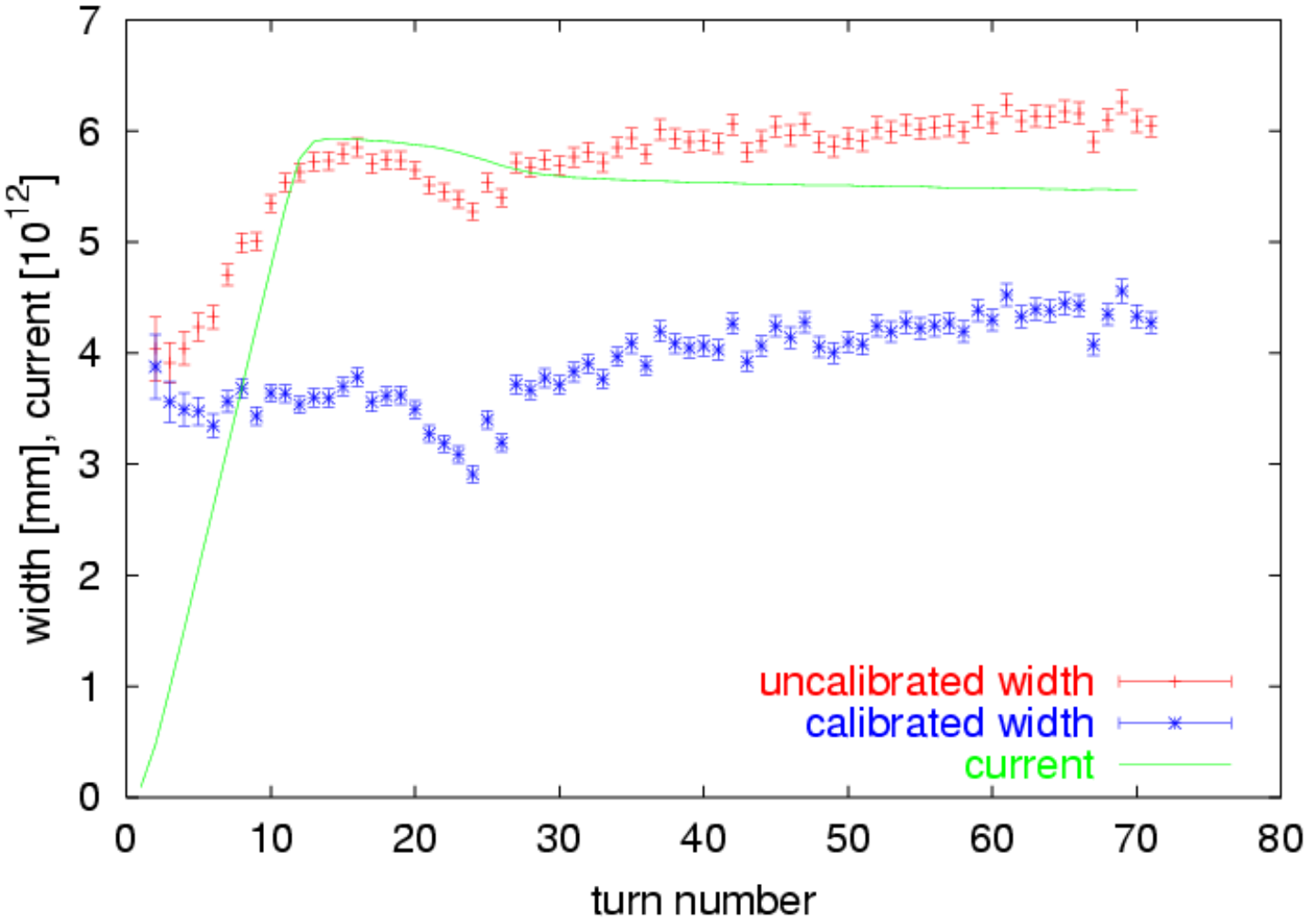




Flying beam wire profiles, good & not-so-good, compared to IPM fitted widths, together with MWPC profiles at extraction (MI8) provide the input to constrain our model of the IPM response (paper submitted to PRSTAB)



IPM calibration results

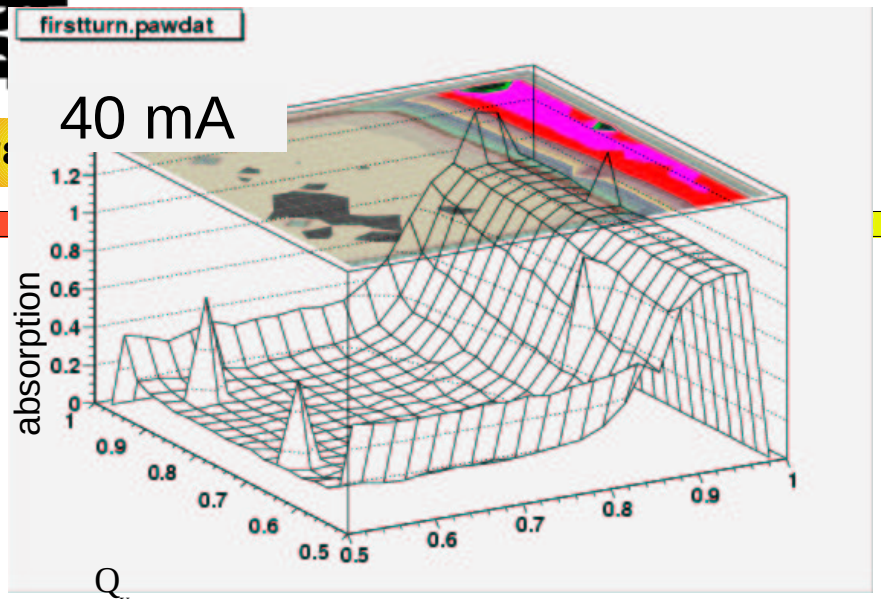


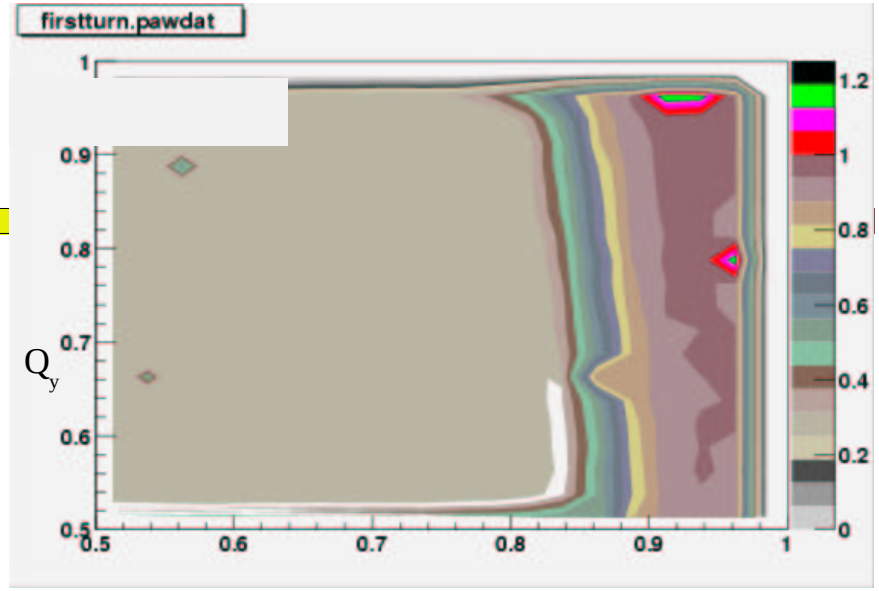
IPM calibration results:

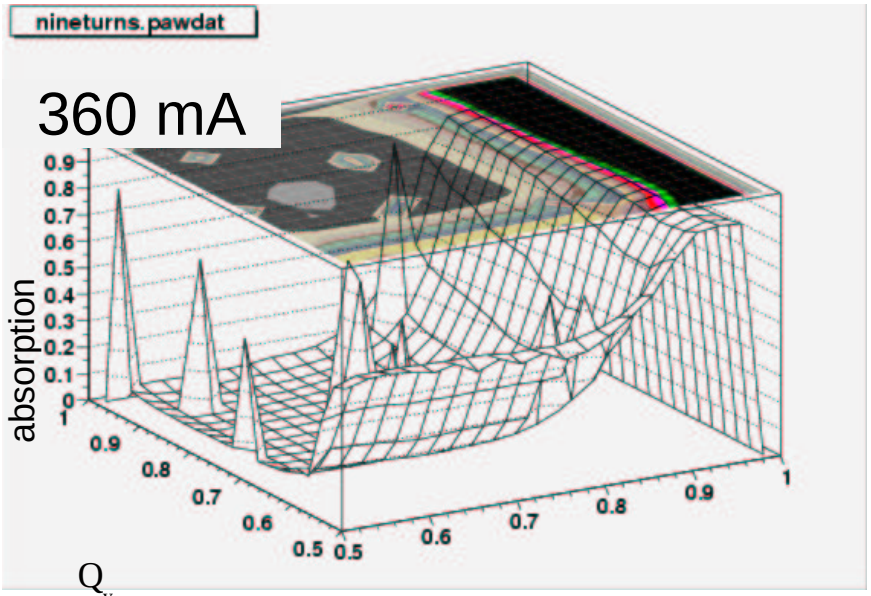
uncalibrated width shows apparent growth at injection correlated with the increase of machine current during injection.

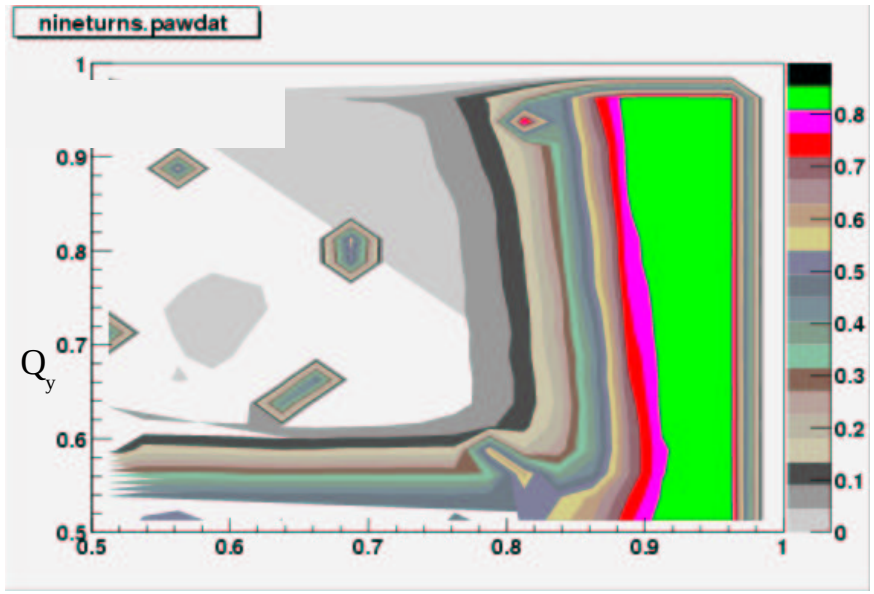
Calibration eliminates this problem.

Resonance Studies









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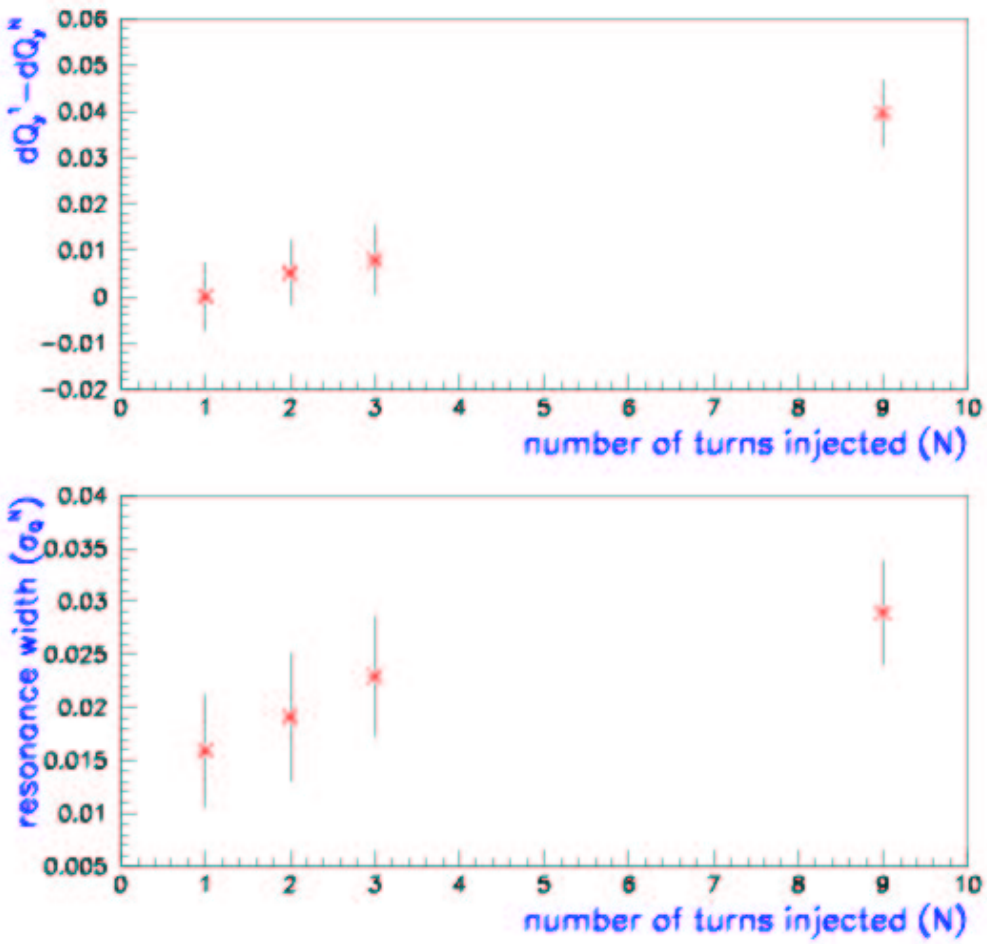
Resonance Studies



Calculating the relationship between measured tune difference (dQ) and the space-charge tune shift (ΔQ_{sc}):

$$Q = Q_0 + \Delta Q_{sc} + \Delta Q_{quad}$$

$$\Delta Q_{quad} = \frac{dQ}{dI}(\Delta I_{quad})$$

$$A: \ \frac{1}{2} = Q_0 + \Delta Q_{sc}^1 + \frac{dQ}{dI}(\Delta I_Q^1)$$

$$B: \ \frac{1}{2} = Q_0 + \Delta Q_{sc}^N + \frac{dQ}{dI}(\Delta I_Q^N)$$

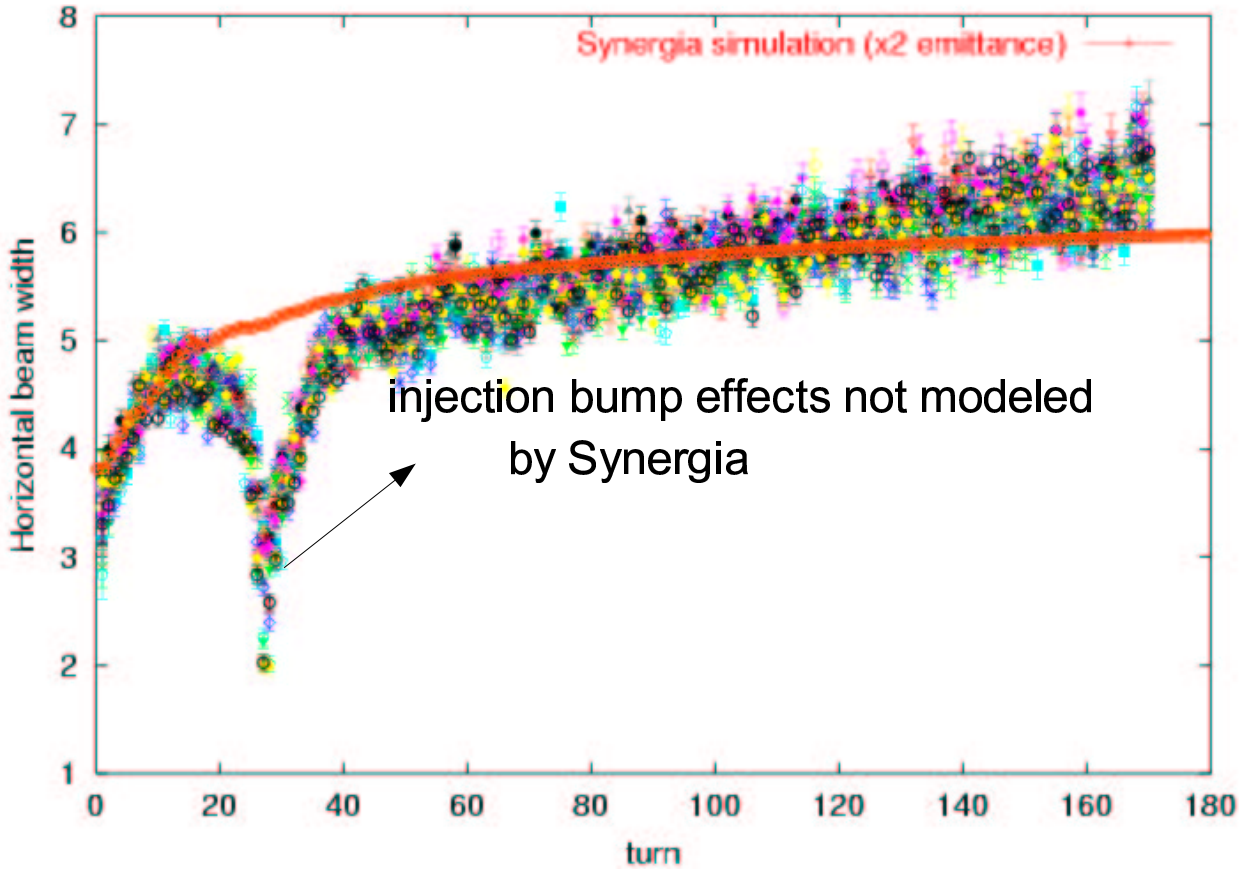
$$B - A: \ 0 = \Delta Q_{sc}^N - \Delta Q_{sc}^1 + \frac{dQ}{dI}(\Delta I_Q^N - \Delta I_Q^1)$$

$$\Delta Q_{sc}^N - \Delta Q_{sc}^1 = \frac{dQ}{dI}(\Delta I_Q^1 - \Delta I_Q^N)$$

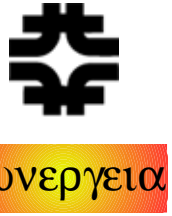
$$\Delta Q_{sc}^N - \Delta Q_{sc}^1 = dQ_{(x/y)}^1 - dQ_{(x/y)}^N$$

Transverse beam width measurements and simulation

Turn-by-turn Ionization Profile Monitor horizontal beam width measurements for 11 turns of injected beam (400 mA total). 15 data sets are displayed. Widths are measured in mm.

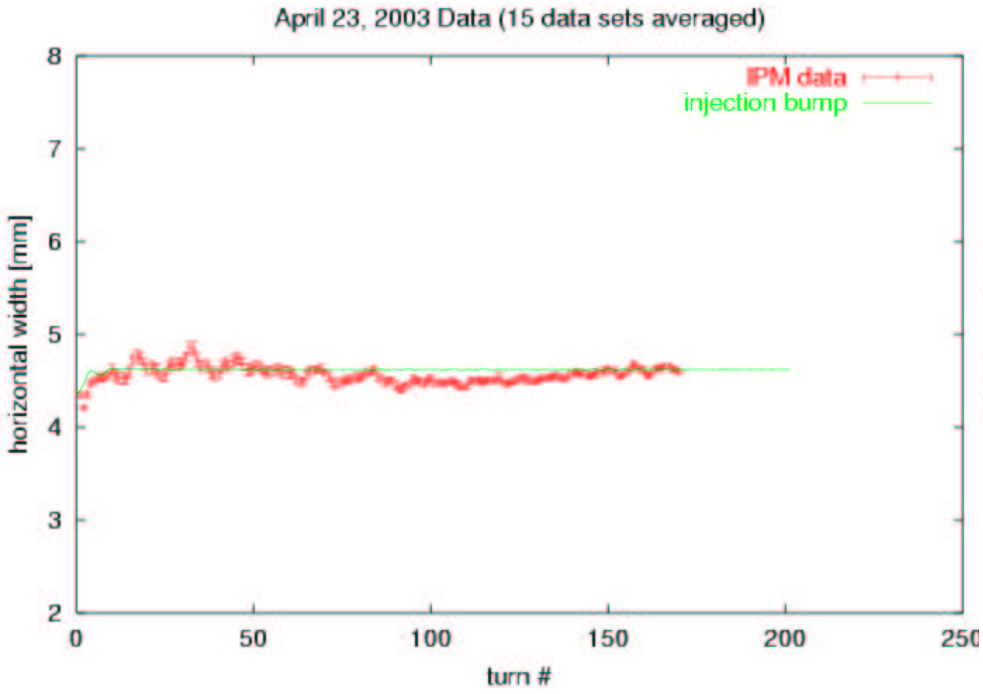


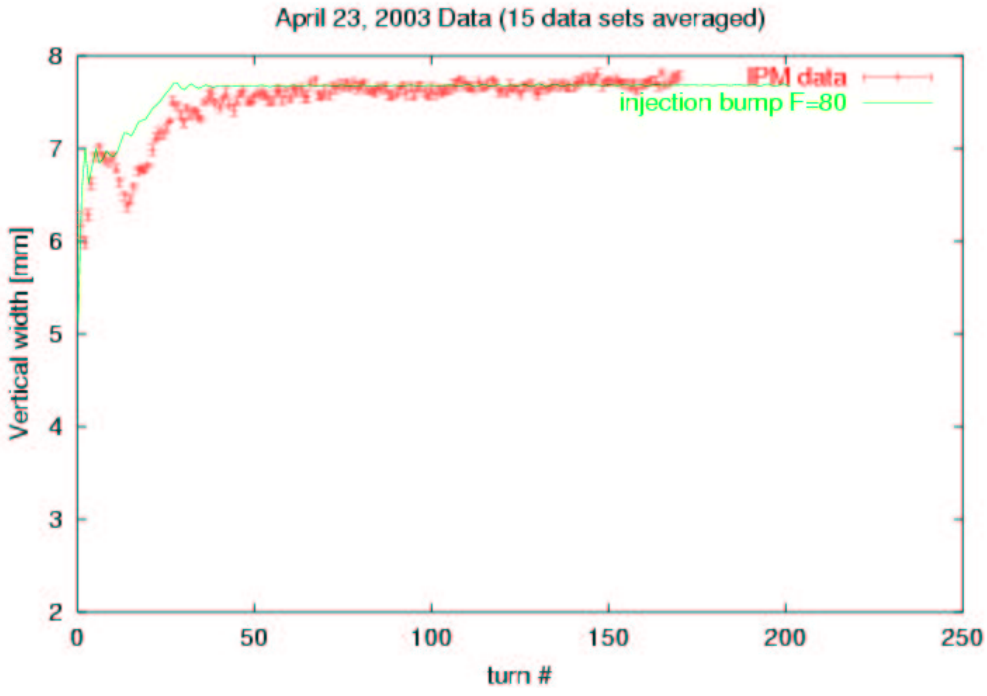
simulated beam with 2 times smaller emittance than nominal Booster emittance



ORBUMP toy model

Synergia simulation including a simple model of the injection bump fringe fields, compared to IPM data at injection, for an optimal (minimal losses & beam disturbance) bump configuration





Simulation reality checks

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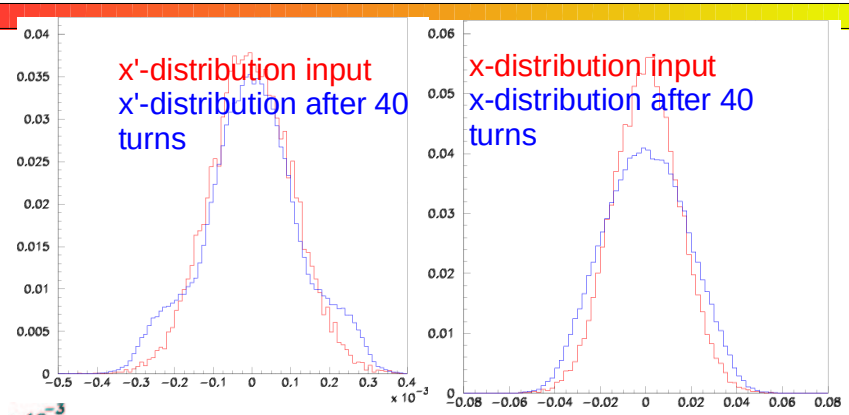

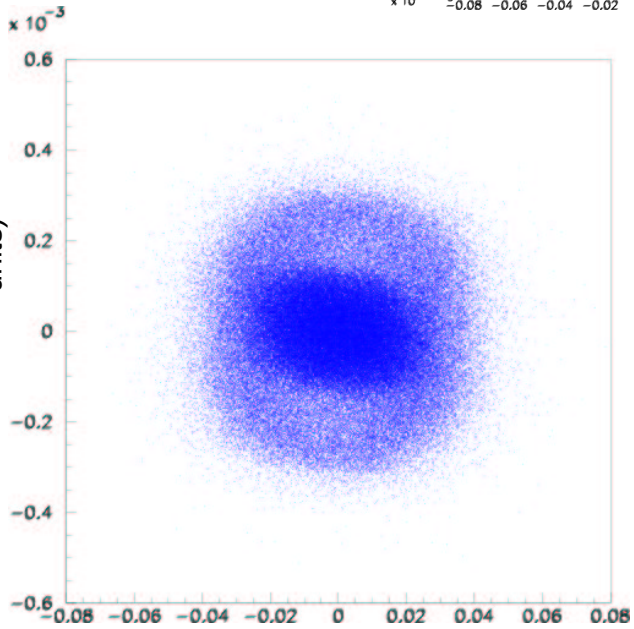

Simulation displays halo growth in the presence of mis-match typical of space charge effects

Simulated transverse phase space projected onto horizontal plane after 40 turns (88 ms)

Mapping Booster response

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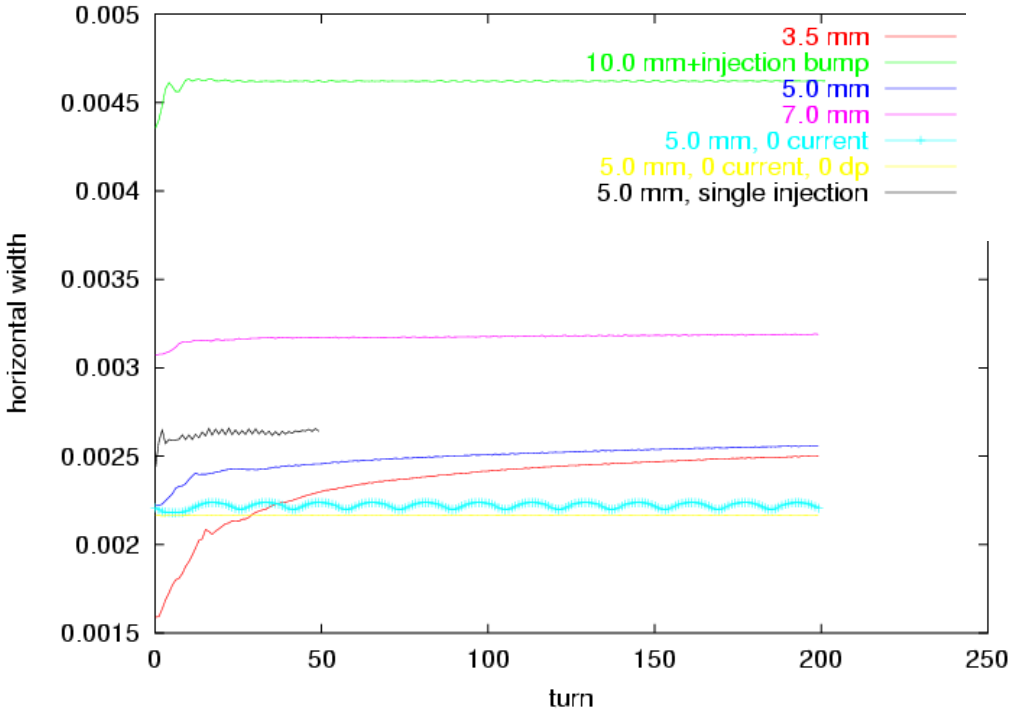

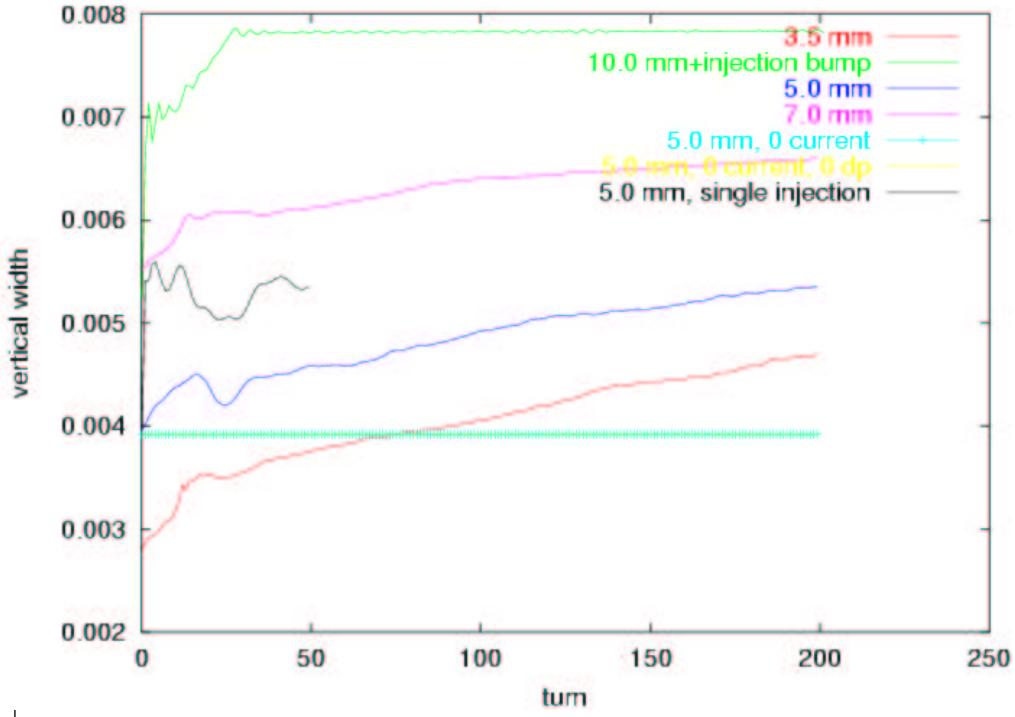

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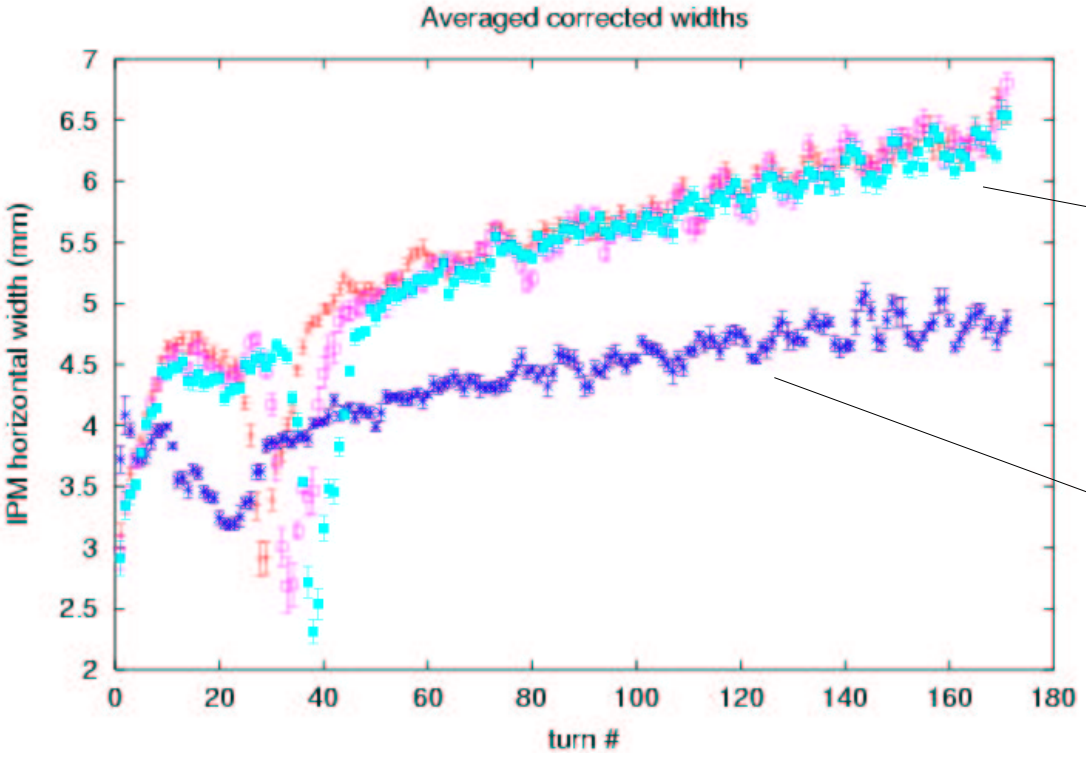
Highlights of IPM data taking

- During our attempt to calibrate the IPM and take data with the detector, we discovered a lot of interesting things…
  - effects of injection bump
  - large variation of machine operation

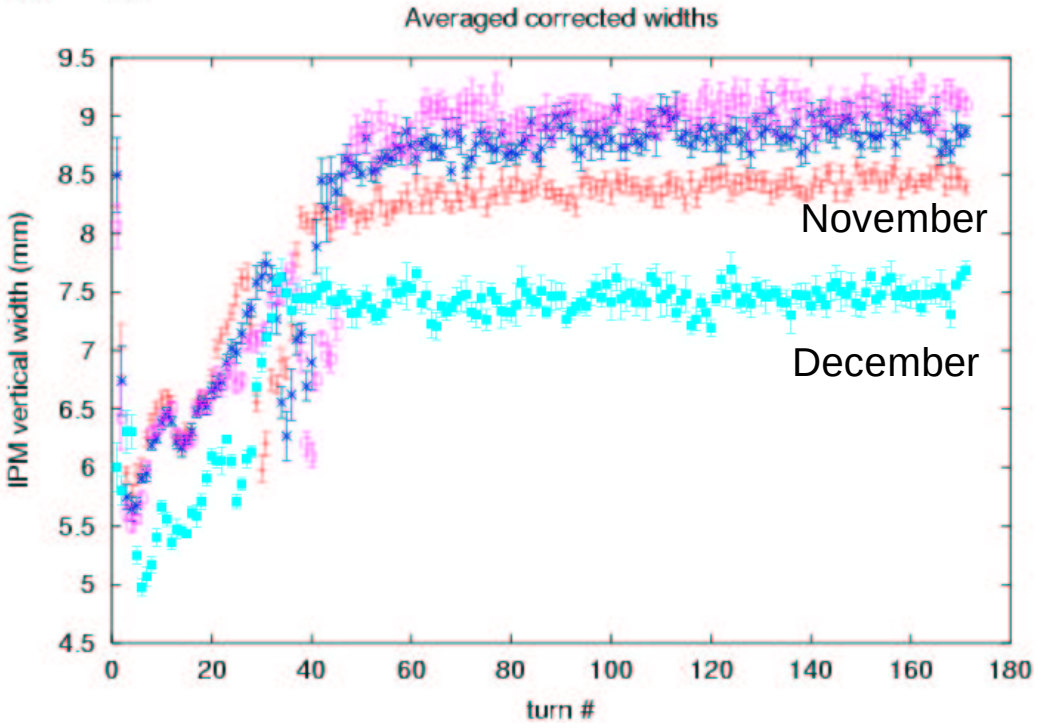
  ⇨ the importance of continuous monitoring

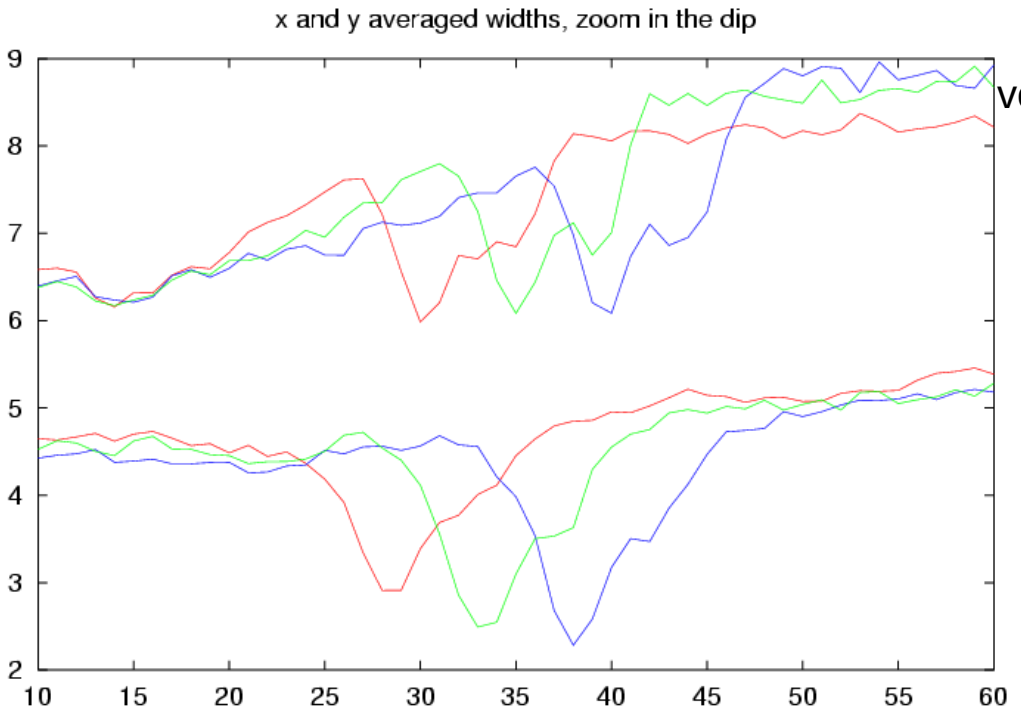


November calibration data.
Flying beam wire is in place
The three data sets have different injection timing with respect to ORBUMP

December calibration data
notice differences at injection

The points shown are the averages of IPM data sets (10-15 per point) taken with the same running conditions. The errors shown are the errors on the mean.





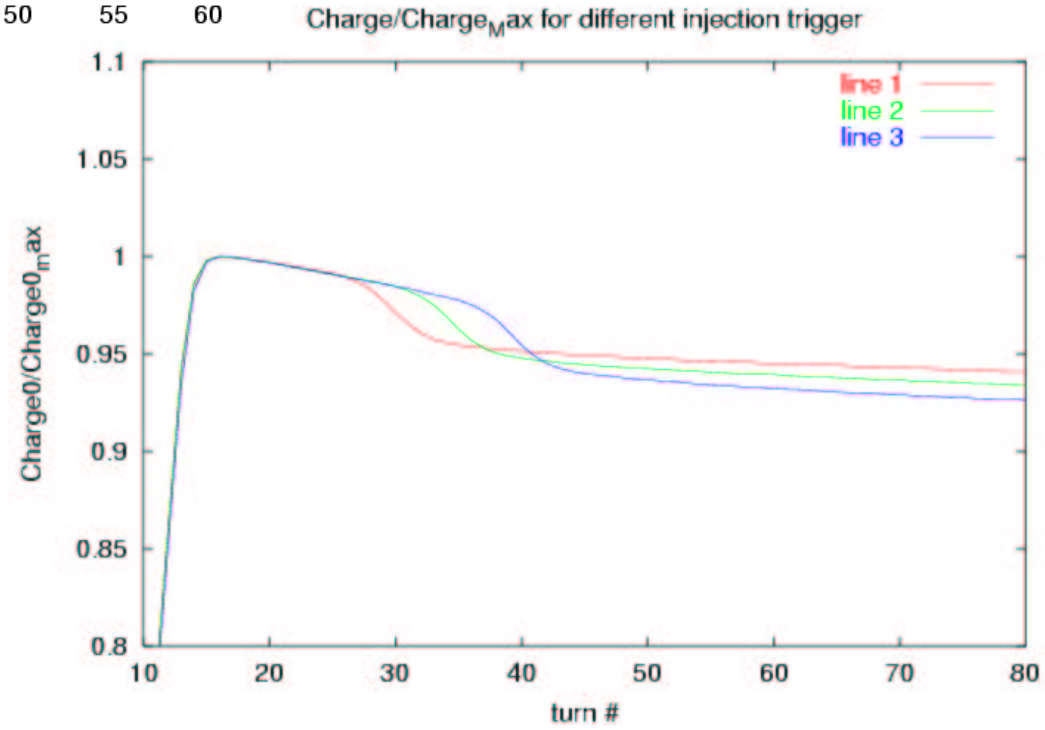
vertical

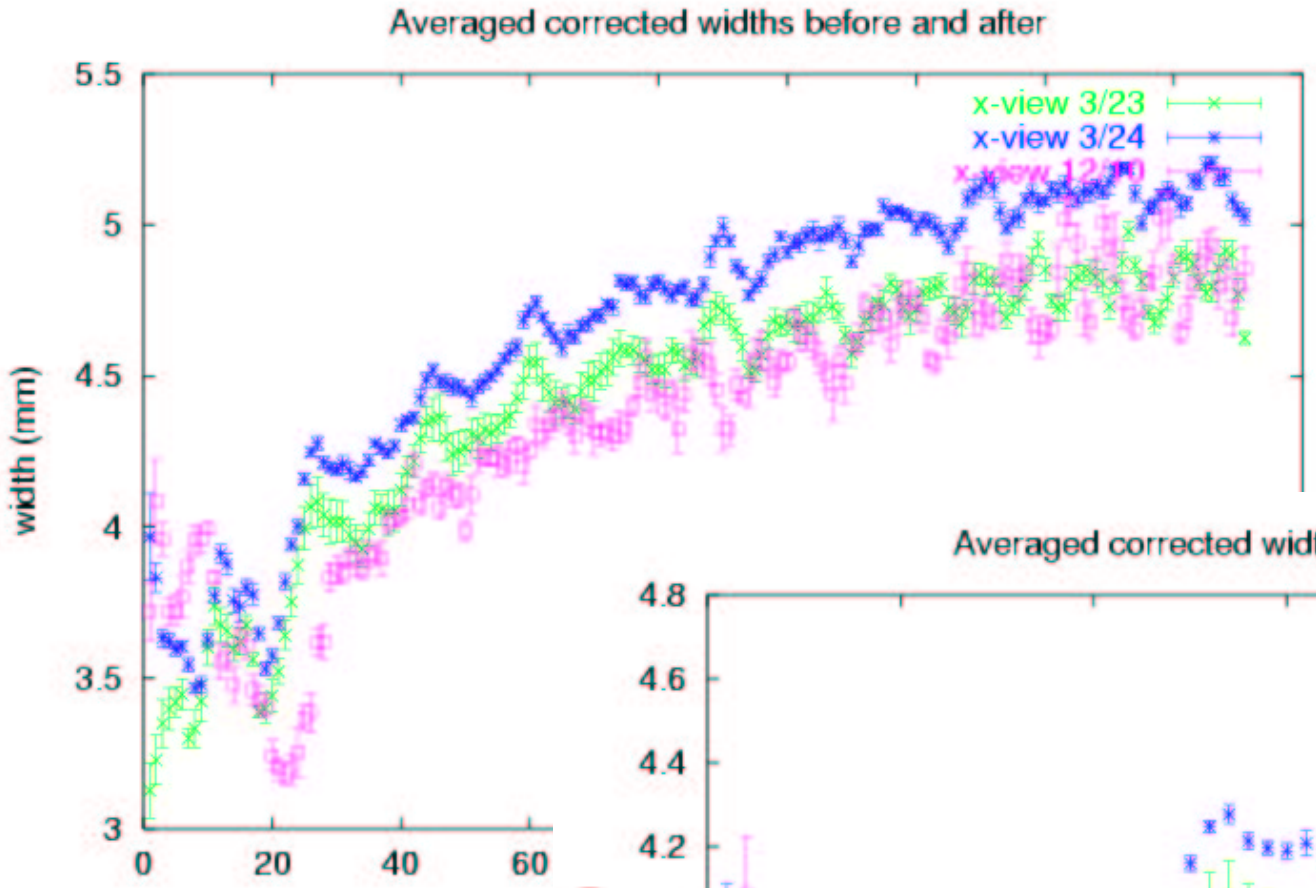
horizontal

November data only zoom in notch region with IPM

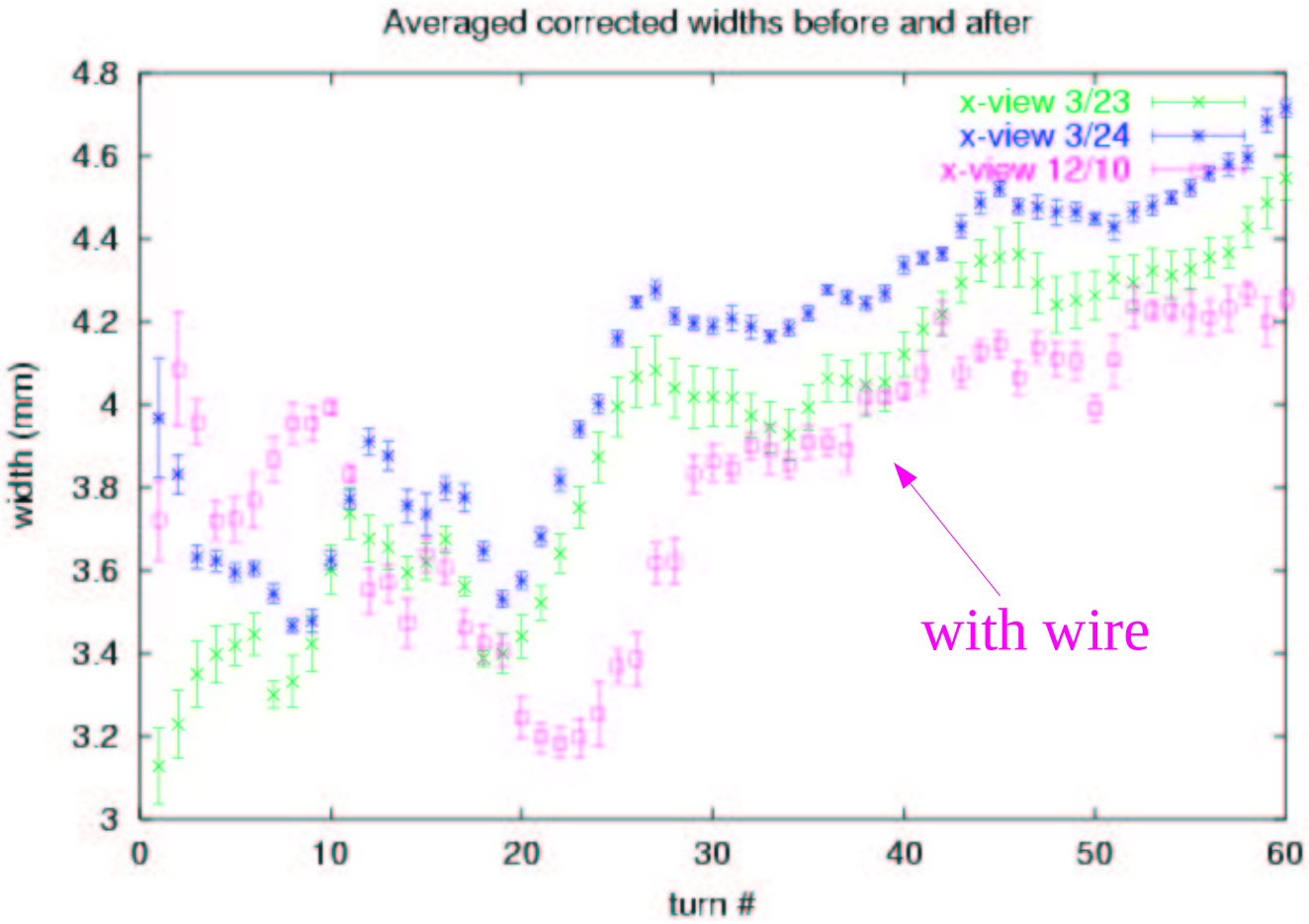
Loss pattern seems to follow “notch”

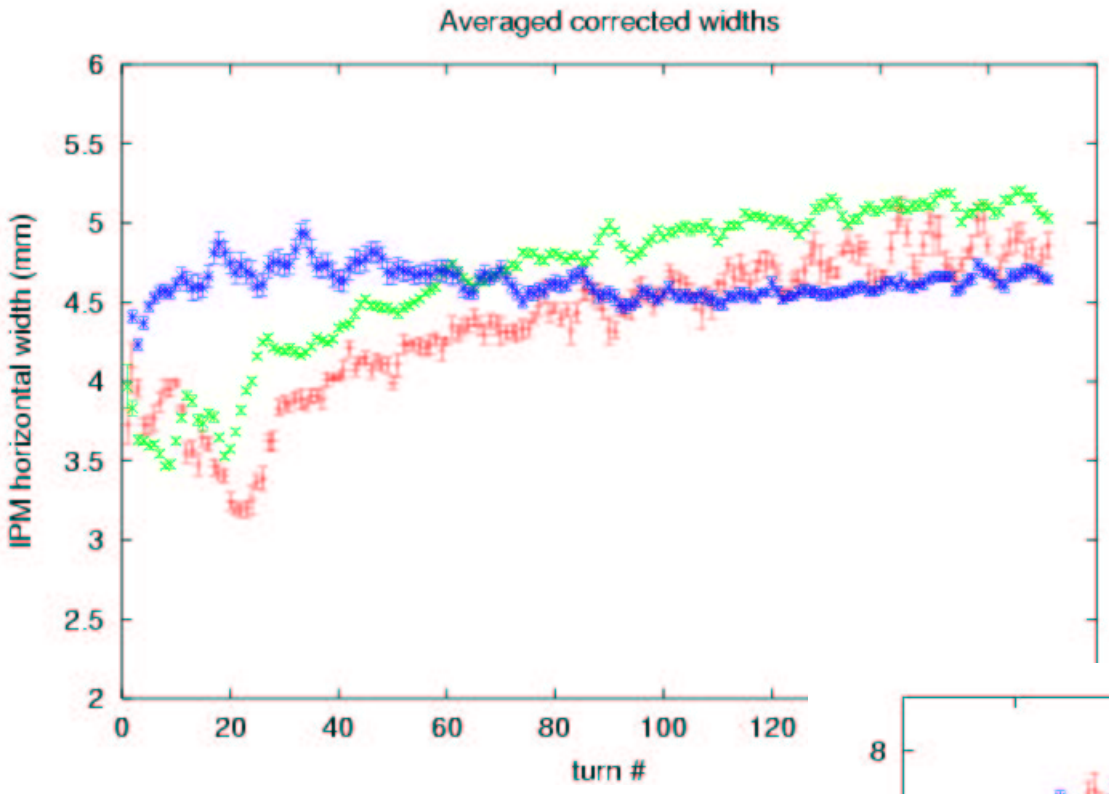
Charge0/Charge0_MAX



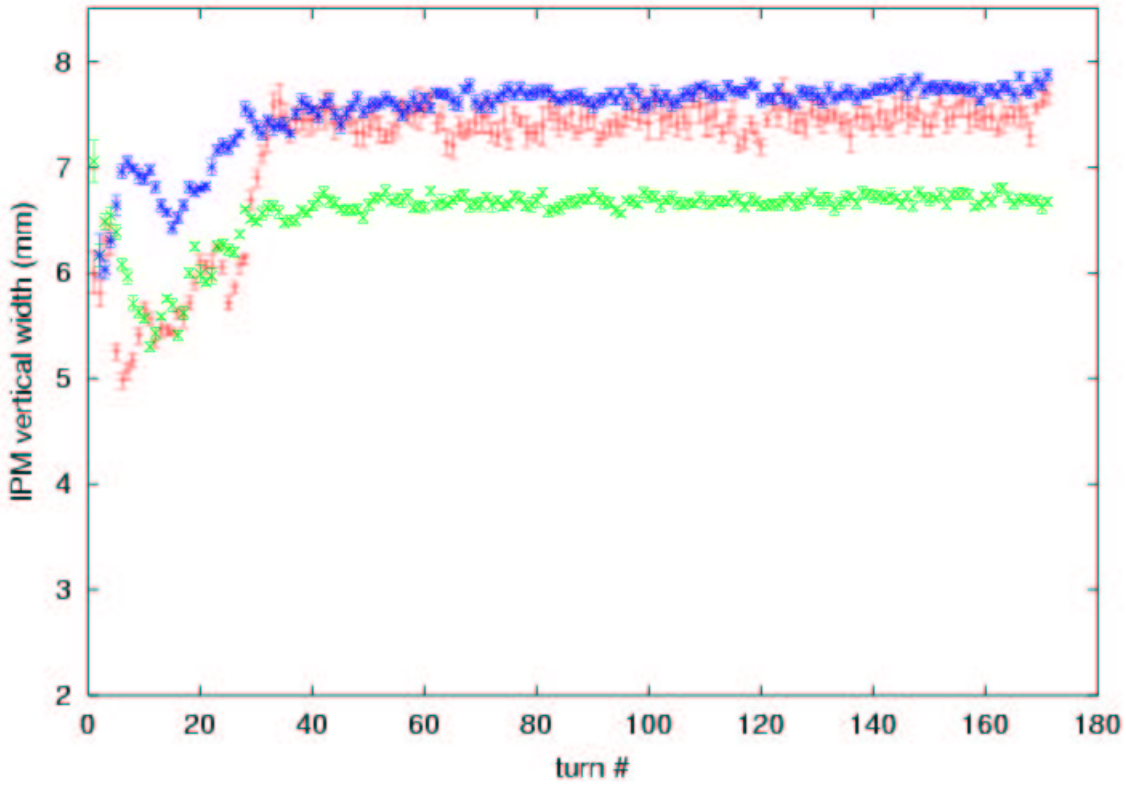


Widths before and after dogleg change
Data sets before change have “flying beam wire present”

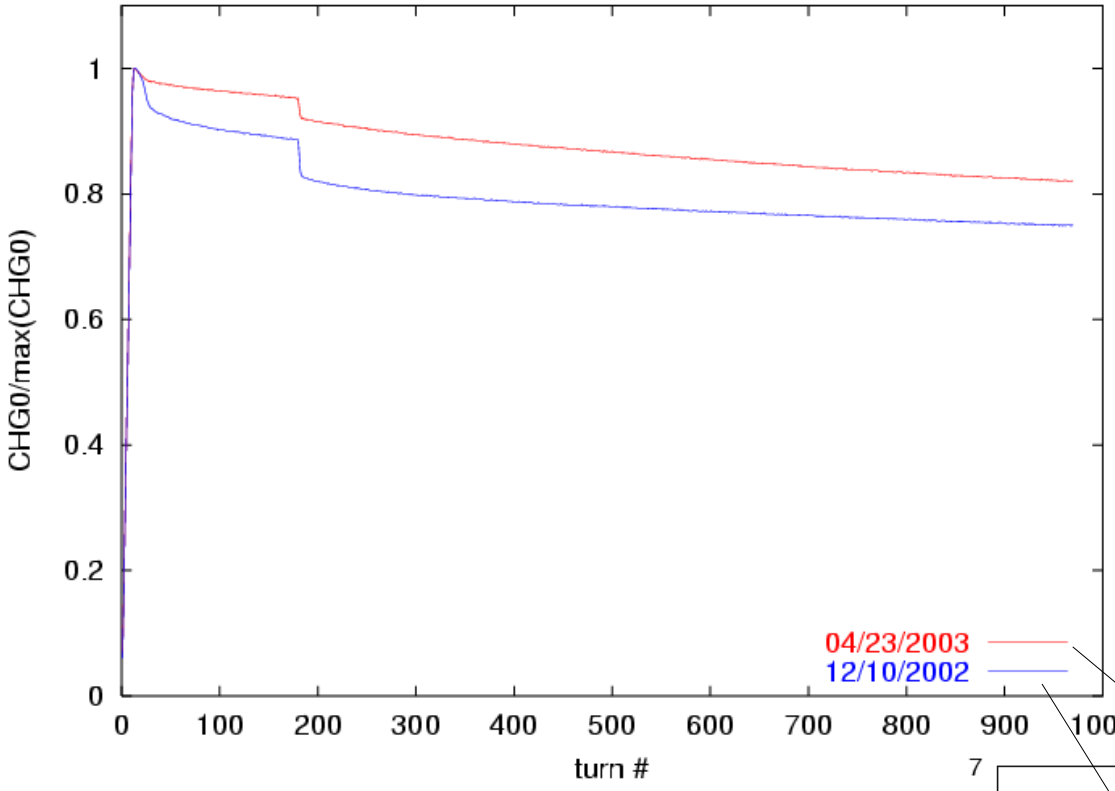


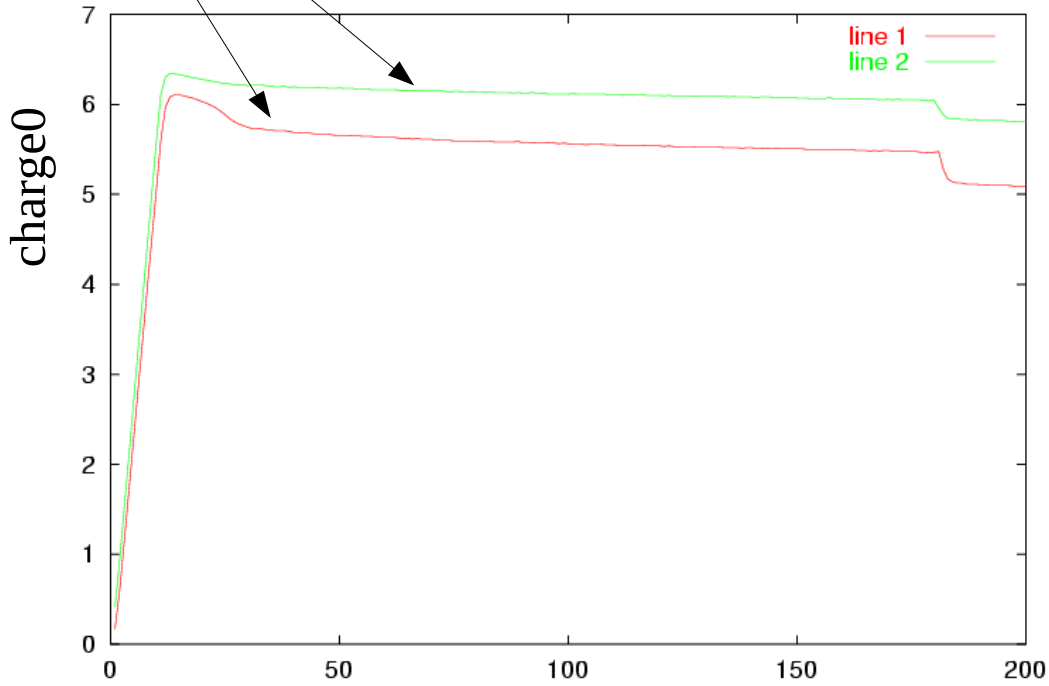


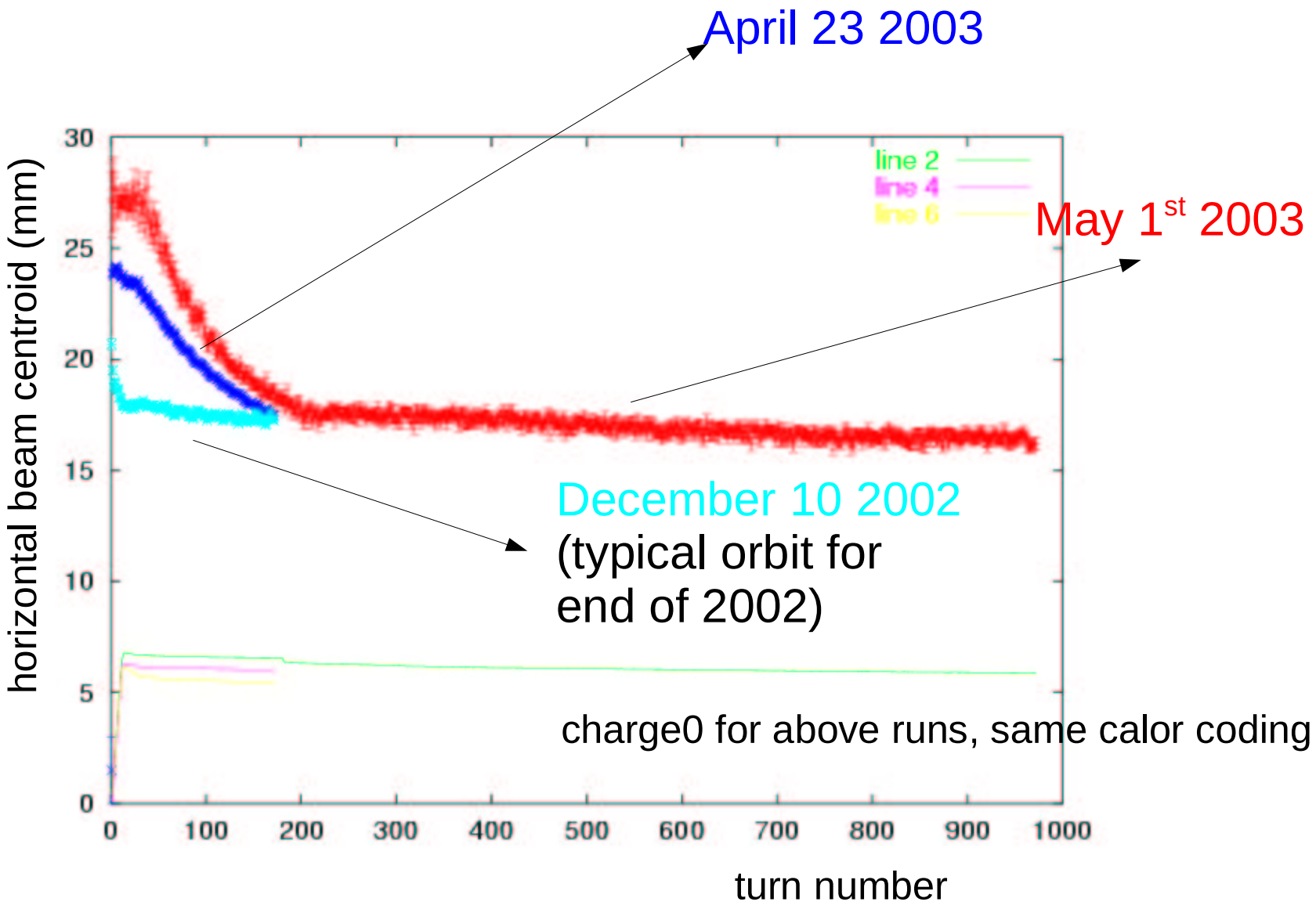
03/25/03 after dogleg
12/10/02 “old” configuration
04/23/03 also ORBUMP shortening



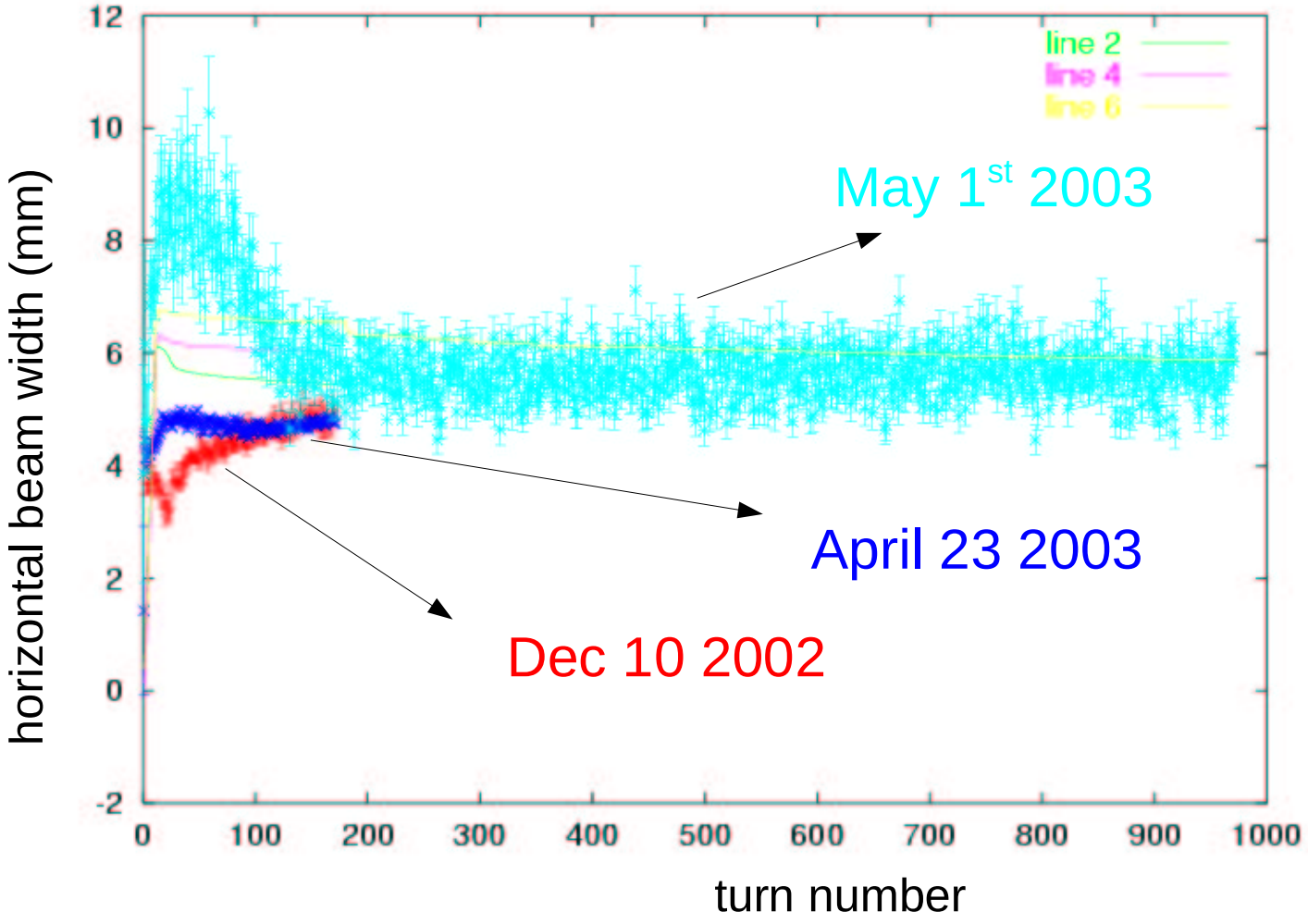
Losses look better!







The Beam likes to run on the outside at injection!
(turned out to be a “local” bump to tune out losses...)


horizontal beam width (mm)
turn number
line 2
line 4
line 6
May 1st 2003
April 23 2003
Dec 10 2002
12
10
8
6
4
2
0
-2
0
100
200
300
400
500
600
700
800
900
1000

Summary

- Have developed the tools needed to monitor Booster with single turn resolution
  - IPM calibration
  - analysis tools for raw IPM data & RWM data
- Have taken data under various conditions (full cycle)
  - have analyzed data ~200 turns after injection and compared to Synergia.
  - qualitative agreement (depending on assumptions)
  - ☞ "conventional" sources & space charge contribute to emittance growth

Summary (2)

- Have analyzed less data than we have collected
  - and it is easy to collect more
- Have modeled fewer cases than we have studied
  - resonance, etc

⇨ It's a manpower/priority issue: we need to keep developing the code, stay on top of the project, etc. Ideally, we should collect data on a regular basis and run different models/cases to match: post-doc?, student?

Plans summary

- Ready to move to phase II of code development
  - will allow to include more physics
  - better flexibility for current studies
- Start proposal work for next cycle of DOE grants
- Would like to continue comprehensive studies/modeling of Booster
  - ⇨ will need help to do studies/run simulations

⇨ Adding more physics capabilities will allow modeling of other machines (& studies, assuming support)